X-592-73-171
PREPRINT

NASA TM X-70422

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(NASA-TM-X-70422) A GLOBAL STATION COORDINATE SOLUTION BASED UPON CAMERA AND LASER DATA - GSFC 1973 (NASA) 71 p HC $5.75 CSCL 14B
N73-28130
Unclas
G3/11 10740

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MAY 1973

GSFC
GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

A GLOBAL STATION COORDINATE SOLUTION BASED UPON CAMERA AND LASER DATA - GSFC 1973

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Presented at the

First International Symposium
The Use of Artificial Satellites for Geodesy and Geodynamics
Athens, Greece
May 14-21, 1973

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ABSTRACT

This paper presents new results obtained at GSFC for the geocentric coordinates of 72 globally distributed satellite tracking stations consisting of 58 cameras and 14 lasers. The observational data for this solution consists of over 65,000 optical observations and more than 350 laser passes recorded during the National Geodetic Satellite Program (NGSP), the 1968 Centre National d'Etudes Spatiales (CNES)/Smithsonian Astrophysical Observatory (SAO) Observing Program, and International Satellite Geodesy Experiment Program (ISAGEX). Dynamical methods were used. The data were analyzed with the GSFC GEM and SAO 1969 Standard Earth Gravity Models. The recent value of GM = 3.986008×10^5 km^3/sec^2 derived at the Jet Propulsion Laboratory (JPL) gave the best results for this combination laser/optical solution. Comparisons of this new solution are made with the deep space solution of JPL (LS-25 solution), results of analysis of lunar laser data recorded at McDonald Observatory, results obtained at GSFC from Mariner-9 Unified S-Band tracking, and interferometric analysis of Apollo Lunar Module tracking data. Comparisons with other near-earth satellite derived solutions are also made. Datum transformation parameters relating the North American, European, South American, Australian and other datums to this reference system are given, enabling the positions of some 200 other tracking stations to be placed in the geocentric system. An uncertainty of the new solution of 5m (1σ) in each coordinate is suggested by the comparisons and an analysis of the error sources.

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1.0 INTRODUCTION

With the advent of artificial satellites, the science of geodesy was provided with a valuable new means of direct earth measurement on a global scale. Some 15 years have passed and in this time, newer instrumentation, computers and techniques have yielded work of high geodetic value. Both operational and purely scientific demands have produced and required information on the size and shape of the Earth and the geopotential. Many experiments using widely varying techniques have derived information on the relative positions of earth based observers, and their locations with respect to the center of mass. The present level of accuracy on a global basis is well below ten meters. This paper presents the results of a global solution for the coordinates of about 70 tracking stations derived with dynamical techniques from precision reduced optical and laser observations of geodetic satellites.

Three recent geodetic satellite observing campaigns have provided a large amount of laser and precision optical tracking data. These were the National Geodetic Satellite Program (NGSP), the 1968 Centre National d'Etudes Spatiales (CNES) - Smithsonian Astrophysical Observatory (SAO) Observing Campaign, and the International Satellite Geodesy Experiment (ISAGEX). Observations recorded during these programs have been used in combination to compute a new global solution for the coordinates of the tracking stations.

Results of dynamic adjustment of station coordinates have been previously reported by the authors (Marsh, Douglas, Klosko, 1971, 1972). These were based primarily upon precision reduced camera observations of the GEOS-I and II flashing lamps. Since the last results were derived, large amounts of additional NGSP optical data and laser data from the

ISAGEX have become available. Also major computer program improvements have been implemented. The new software provided the opportunity to combine laser and optical data with all stations adjusted simultaneously without constraints, rather than in groups as before. Furthermore, our preliminary error analysis indicated that a large simultaneous solution as performed required no initial constraints relating the stations to the geocenter. To assure this independence from other solutions, the a priori variances of all station coordinates were taken to be 100,000 m^2. The a posteriori variances from the least-squares adjustement were generally $3m^3$ or less.

The amount of new data is substantial. In addition to the laser data, the new solution contains approximately 5000 additional GEOS-I and II camera observations recorded by NGSP European Observatories. This data set consists of observations made available to us by the Malvern, Uzhgorod, Delft and Helsinki Observatories. The laser data contributed additional precise scale information to the optical solution, and also provided recovery for two new areas of the world, Guam Island and Dakar, Senegal.

The NONAME Orbit and Geodetic Parameters Estimation (Martin, C.F. and O'Neill, 1968) System used previously restricted the maximum number of stations which could be adjusted simultaneously to twenty. In order to overcome this limitation, previous results were derived in a step-wise fashion. The GEODYN Computer Program System (Martin, T.V., 1972) used in the present analyses did not contain this limitation and permitted the simultaneous adjustment of all stations.

As before, we evaluate our results by making comparisons wherever possible with independent results obtained by other experimenters. A more comprehensive evaluation of results is now possible through the independent geodetic values derived from; Mariner-9 Unified S-Band tracking data, lunar laser data recorded at McDonald Observatory, Apollo Lunar Module tracking data and detailed gravimetric geoid heights based upon a combination of satellite and surface gravity data and others. These comparisons are of great significance because some of the independent solutions for station coordinates are independent of the geopotential.

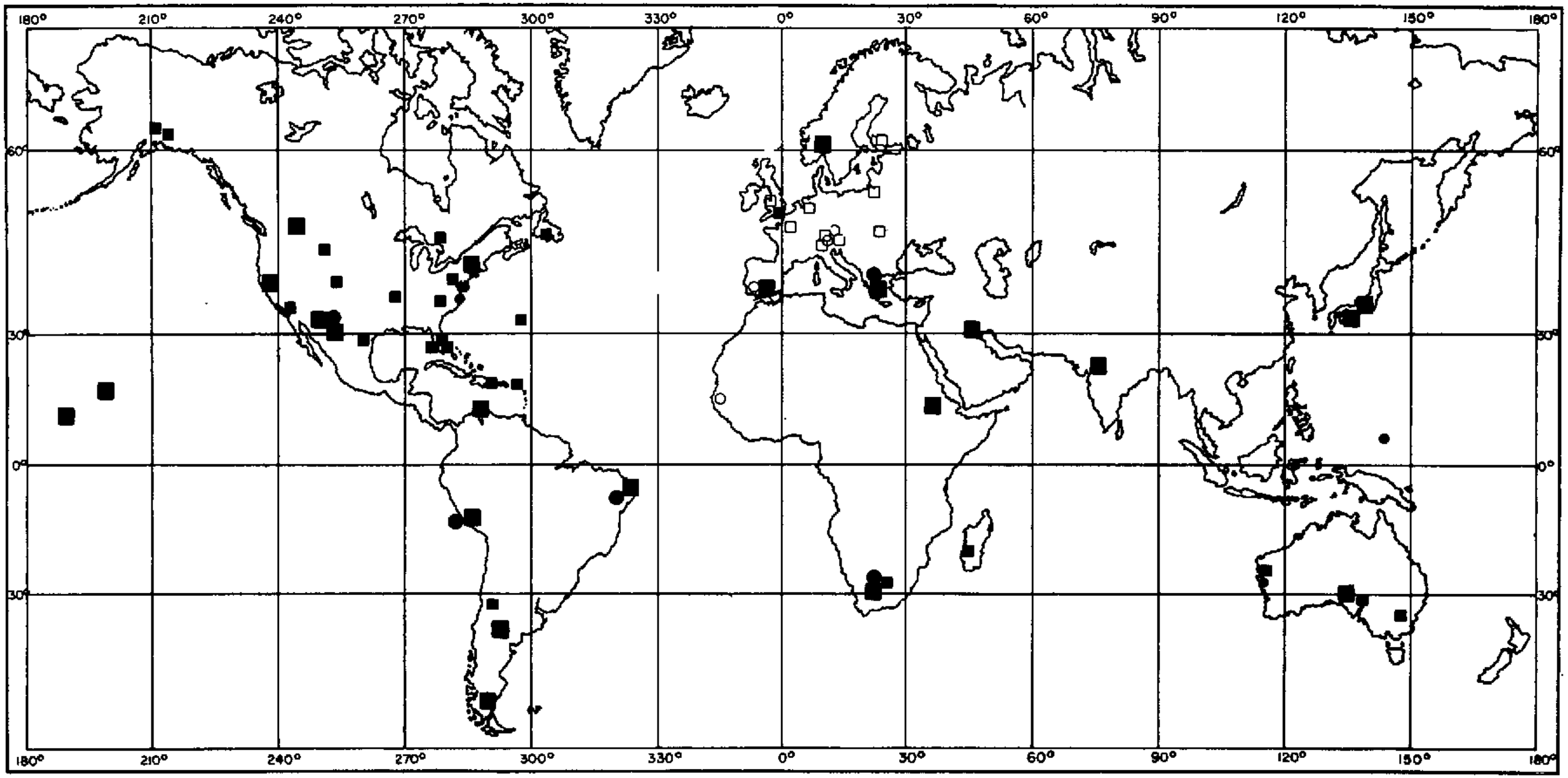
2.0 DESCRIPTION OF SOLUTIONS

Figure 1 shows the geographic locations of the optical and laser sites which contributed observations for this solution. Data from BE-C, GEOS-I, GEOS-II, D1-C and D1-D were used in this work. Table 1 presents the values for our recovered stations referred to elsewhere in this text as GSFC '73.

The solutions were derived through the use of the GEODYN program on the GSFC IBM 360/95 computer. GEODYN is a multiple arc, multiple satellite orbit and geodetic parameter estimation system based upon Cowell type numerical integration techniques. Model parameters included luni-solar gravitational perturbations, solar radiation pressure, BIH polar motion and UT1 data, and several different sets of geopotential coefficients. While the effects of solid Earth tides are modeled by the program, they were not considered in this analysis since the potential model solutions did not account for them.

A total of 150 two-day arcs were used in the final simultaneous solution. Experience with the GEOS flash observations and laser data has indicated that two-day arcs are short enough to accommodate model errors yet long enough to provide adequate dynamical strength. The dominant error source for this work was uncertainty in the values of the 12th and 13th order resonant coefficients of the gravitational model. Resonance produces an orbital perturbation of about 600 meters, primarily along track, on the GEOS satellites with a period of about six days. Resonance errors on the order of a few tens of meters were for the most part absorbed in the two day orbital elements. To further reduce unmodeled orbital error, passes were selected to be in all directions on all sides of the stations which lead to favorable cancellation of errors.

FIGURE 1. GEOGRAPHIC LOCATION OF TRACKING STATIONS
FOR THE GSFC'73 SOLUTION



■ *NASA camera*
■ *SAO camera*
□ *International camera*
● *NASA laser*
● *SAO laser*
○ *GRGS (French) laser*

Table 1

GSFC '73 Adjusted Station Coordinates

Station Name	Number	Earth Fixed Rectangular Coordinates X (M)	Y (M)	Z (M)	Standard Deviation X (M)	Y (M)	Z (M)
1BPOIN	1021	1118044.28	-4876311.20	3942969.13	1.58	1.66	2.13
1FTMYR	1022	807878.54	-5651976.34	2833509.48	0.98	0.74	1.47
1OOMER	1024	-3977283.19	3725645.25	-3302982.36	0.99	0.96	1.39
1SATAG	1028	1769720.15	-5044611.18	-3468254.13	1.24	1.29	1.65
1MOJAV	1030	-2357233.29	-4646330.63	3668317.01	0.90	0.76	1.40
1JOBUR	1031	5084792.27	2670410.49	-2768141.79	0.97	1.14	1.46
1NEWFL	1032	2602772.46	-3419140.86	4697664.13	2.54	4.10	3.31
1COLEG	1033	-2299250.39	-1445693.00	5751809.47	3.56	5.96	4.32
1GFORK	1034	- 521691.57	-4242046.85	4718728.68	0.98	0.84	1.38
1WNKFL	1035	3983118.58	- 48493.59	4964720.04	1.39	1.25	1.73
1ULASK	1036	-2282349.12	-1452644.04	5756898.95	2.55	2.39	3.10
1ROSMN	1037	647538.79	-5177924.35	3656711.95	0.97	0.77	1.44
1ORORL	1038	-4447490.66	2677168.66	-3695059.08	1.35	1.46	1.60
1ROSMA	1042	647531.24	-5177925.13	3656712.41	0.97	0.77	1.44
1TANAN	1043	4091870.67	4434292.77	-2064723.14	1.65	1.58	1.93
1UNDAK	7034	- 521691.57	-4242046.85	4718728.68	0.98	0.84	1.38
1EDINB	7036	- 828475.36	-5657454.18	2816822.13	1.07	0.86	1.57
1COLBA	7037	- 191271.65	-4967275.43	3983264.16	0.95	0.74	1.40
1BERMD	7039	2308235.18	-4873589.40	3394578.32	1.09	1.04	1.62
1PURIO	7040	2465075.10	-5534913.57	1985524.52	1.11	0.99	1.68
1DENVR	7045	-1240461.34	-4760228.83	4048990.72	0.97	0.84	1.44
GODLAS	7050	1130687.92	-4831357.28	3994109.28	1.21	0.83	1.34
WALLAS	7052	1261564.16	-4881571.83	3893172.13	1.36	1.32	1.47

Table 1 (Continued)

Station Name	Number	X (M)	Y (M)	Z (M)	SD X (M)	SD Y (M)	SD Z (M)
		Earth Fixed Rectangular Coordinates			Standard Deviation		
CRMLAS	7054	-2328182.35	5299650.40	-2669473.46	1.77	1.14	1.88
GMILAS	7060	-5068969.11	3584090.31	1458761.92	1.47	1.95	1.72
1JUM24	7071	976287.90	-5601398.33	2880235.06	1.51	1.45	1.99
1JUM40	7072	976291.83	-5601391.98	2880246.34	1.51	1.45	1.99
1SUDBR	7075	692631.93	-4347062.15	4600486.87	1.19	1.11	1.56
1JAMAC	7076	1384177.17	-6905663.00	1966543.85	1.22	1.08	1.75
1CARVN	7079	-2328597.68	5299360.83	-2669665.62	1.77	1.14	1.88
DAKLAS	7820	5886270.08	-1845641.58	1615263.13	2.56	3.74	3.21
DELFTH	8009	3923403.21	299905.17	5002984.93	1.72	1.44	1.88
ZIMWLD	8010	4331308.98	567539.81	4633129.26	1.23	1.31	1.84
MALVRN	8011	3920166.80	- 134710.63	5012735.01	2.34	1.74	2.25
HAUTEP	8015	4578327.29	457994.69	4403201.69	0.74	1.01	1.26
HAULAS	7809	4578347.92	457985.79	4403179.81	0.74	1.01	1.26
HAUTLS	89	4578370.29	457978.93	4403157.43	0.74	1.01	1.26
NICEFR	8019	4579478.08	586629.42	4386427.12	1.40	1.37	1.78
MUDONI	8030	4205641.08	163743.17	4776557.11	2.11	1.76	2.39
1ORGAN	9001	-1535737.62	-5167004.17	3401046.39	1.21	1.12	1.72
1OLFAN	9002	5056128.71	2716523.00	-2775768.38	0.83	1.07	1.38
OLILAS	7902	5056126.96	2716522.07	-2775767.42	0.83	1.07	1.38
1SPAIN	9004	5105593.50	- 555216.21	3769676.43	0.70	0.94	1.27
SAFLAS	7804	5105613.60	- 555238.49	3769645.13	0.70	0.94	1.27
SAFLAS	80	5105613.60	-555238.49	3769645.13	0.70	0.94	1.27
1TOKYO	9005	-3946711.01	3366270.13	3698831.44	2.70	4.27	3.05
1NATOL	9006	1018186.61	5471109.36	3109620.35	2.20	1.96	2.58

Table 1 (Continued)

Station Name	Number	Earth Fixed Rectangular Coordinates X (M)	Y (M)	Z (M)	Standard Deviation X (M)	Y (M)	Z (M)
1QUIPA	9007	1942789.38	-5804078.88	-1796924.28	1.18	0.81	1.54
ARELAS	7907	1942789.54	-5804079.35	-1796924.43	1.18	0.81	1.54
1SHRAZ	9008	3376865.40	4404000.16	3136262.06	3.68	4.04	4.06
1CURAC	9009	2251853.44	-5816914.68	1327172.04	2.76	3.26	3.46
1VILDO	9011	2280592.01	-4914577.49	-3355407.84	1.36	1.21	1.67
1MAUIO	9012	-5466048.05	-2404310.04	2242187.75	1.23	1.27	1.70
HOPKIN	9021	-1936767.24	-5077711.90	3331918.44	1.33	1.05	1.66
HOPLAS	7921	-1936766.10	-5077708.34	3331923.32	1.33	1.05	1.66
AUSBAK	9023	-3977785.39	3725102.02	-3303006.37	0.99	0.96	1.39
DODAIR	9025	-3910455.14	3376332.59	3729216.75	2.70	4.27	3.05
DEZEIT	9028	4903748.22	3965226.77	963868.91	1.83	1.99	2.09
NATALB	9029	5186473.14	-3653859.90	- 654326.87	1.45	1.70	2.03
NATLAS	7929	5186473.65	-3653860.26	- 654326.93	1.45	1.70	2.03
COMRIV	9031	1693806.56	-4112337.96	-4556644.76	1.69	1.91	2.00
AGASSI	9050	1489751.00	-4467467.86	4287310.20	4.15	4.13	4.30
GREECE	9091	4595161.99	2039475.58	3912666.88	1.04	1.17	1.55
GRELAS	7930	4595219.45	2039457.97	3912620.41	1.04	1.17	1.55
COLDLK	9424	-1264826.52	-3466881.64	5185469.29	4.27	5.03	5.32
EDWAFB	9425	-2449996.16	-4624428.96	3635038.09	1.55	1.53	2.15
OSLONR	9426	3121260.13	592666.09	5512723.84	8.23	5.60	7.79
JOHNST	9427	-6007395.09	-1111889.86	1825744.67	2.88	3.40	3.50
RIGALA	9431	3183880.77	1421486.63	5322812.71	1.92	1.41	1.73
UZHGOR	9432	3907413.47	1602446.82	4763922.11	1.45	1.45	1.88
HELSIK	9435	2884532.38	1342146.05	5509530.97	2.92	2.13	2.38

Table 1 (Continued)

Station Name	Number	Geodetic Coordinates* Geodetic Latitude (Deg, Min, Sec)	East Longitude (Deg, Min, Sec)	Height (Meters)	Standard Deviation Lat (Sec)	Lon (Sec)	Ht (M)
1BPOIN	1021	38 25 49.826	282 54 49.027	- 50.26	0.061	0.066	1.93
1FTMYR	1022	26 32 53.336	278 8 4.582	- 36.87	0.046	0.036	0.81
1OOMER	1024	-31 23 25.041	136 52 15.828	123.10	0.044	0.041	0.89
1SATAG	1028	-33 8 58.452	289 19 53.702	705.21	0.052	0.049	1.33
1MOJAV	1030	35 19 47.914	243 5 59.462	886.09	0.043	0.037	0.85
1JOBUR	1031	-25 53 0.900	27 42 26.547	1534.93	0.047	0.041	1.01
1NEWFL	1032	47 44 29.639	307 16 46.883	67.64	0.088	0.153	4.08
1COLEG	1033	64 52 18.268	212 9 37.190	156.20	0.121	0.363	5.46
1GFORK	1034	48 1 21.332	262 59 20.064	213.47	0.038	0.047	1.10
1WNKFL	1035	51 26 45.970	359 18 8.895	100.80	0.044	0.065	1.76
1ULASK	1036	64 58 36.948	212 28 31.733	287.51	0.078	0.197	3.05
1ROSMN	1037	35 12 7.330	277 7 41.756	861.79	0.044	0.039	0.90
1ORORL	1038	-35 37 32.012	148 57 14.927	941.43	0.052	0.054	1.45
1ROSMA	1042	35 12 7.345	277 7 41.456	861.92	0.044	0.039	0.90
1TANAN	1043	-19 0 31.858	47 17 59.420	1356.32	0.061	0.056	1.64
1UNDAK	7034	48 1 21.332	262 59 20.064	213.47	0.038	0.047	1.10
1EDINB	7036	26 22 46.733	261 40 7.840	20.35	0.049	0.039	0.95
1COLBA	7037	38 53 36.179	267 47 41.417	225.04	0.042	0.039	0.91
1BERMD	7039	32 21 49.787	295 20 35.615	- 16.84	0.050	0.043	1.12
1PURIO	7040	18 15 28.771	294 0 24.034	- 9.46	0.053	0.039	1.03
1DENVR	7045	39 38 48.065	255 23 39.119	1759.45	0.042	0.041	1.01
GODLAS	7050	39 1 14.268	283 10 18.955	2.46	0.044	0.051	0.74
WALLAS	7052	37 51 36.191	284 29 24.506	- 49.68	0.056	0.055	1.00
CRMLAS	7054	-24 54 15.609	113 42 58.681	- 1.46	0.063	0.065	0.92

*a_e = 6378155.m, 1/f = 298.255

Table 1 (Continued)

Station Name	Number	Geodetic Coordinates*			Standard Deviation		
		Geodetic Latitude (Deg, Min, Sec)	East Longitude (Deg, Min, Sec)	Height (Meters)	Lat (Sec)	Lon (Sec)	Ht (M)
GMILAS	7060	13 18 33.581	144 44 13.951	126.82	0.055	0.077	0.80
1JUM24	7071	27 1 13.868	279 53 13.092	- 31.04	0.061	0.055	1.60
1JUM40	7072	27 1 14.277	279 53 13.272	- 30.89	0.061	0.055	1.60
1SUDBR	7075	46 27 21.352	279 3 10.907	230.50	0.044	0.056	1.33
1JAMAC	7076	18 4 34.515	283 11 27.437	415.28	0.056	0.042	1.12
1CARVN	7079	-24 54 22.615	113 43 16.381	- 9.46	0.063	0.065	0.92
DAKLAS	7820	14 46 3.458	342 35 28.210	28.69	0.115	0.123	2.21
DELFTH	8009	52 0 6.468	4 22 16.292	56.54	0.053	0.076	1.95
ZIMWLD	8010	46 52 37.225	7 27 54.171	941.68	0.048	0.063	1.63
MALVRN	8011	52 8 36.002	358 1 54.808	145.02	0.058	0.092	2.69
HAUTEP	8015	43 55 57.739	5 42 45.360	691.16	0.040	0.046	0.77
HAULAS	7809	43 55 56.787	5 42 44.871	690.13	0.040	0.046	0.77
HAUTLS	89	43 55 55.780	5 42 44.465	690.14	0.040	0.046	0.77
NICEFR	8019	43 43 32.980	7 17 59.324	415.51	0.052	0.062	1.59
MUDONI	8030	48 48 22.175	2 13 46.696	205.89	0.059	0.087	2.60
1ORGAN	9001	32 25 24.805	253 26 49.169	1615.84	0.052	0.047	1.24
1OLFAN	9002	-25 57 36.013	28 14 52.626	1558.13	0.045	0.040	0.78
OLILAS	7902	-25 57 36.013	28 14 52.626	1555.92	0.045	0.040	0.78
1SPAIN	9004	36 27 46.764	353 47 37.190	56.48	0.041	0.038	0.71
SAFLAS	7804	36 27 45.516	353 47 36.388	55.88	0.041	0.038	0.71
SAFLAS	80	36 27 45.516	353 47 36.388	55.88	0.041	0.038	0.71
1TOKYO	9005	35 40 22.708	139 32 17.258	78.41	0.112	0.131	3.46
1NATOL	9006	29 21 34.473	79 27 27.796	1863.09	0.077	0.081	2.21
1QUIPA	9007	-16 27 56.834	288 30 24.664	2476.01	0.049	0.040	0.83

*a_e = 6378155. m, 1/f = 298.255

Table 1 (Continued)

Station Name	Number	Geodetic Coordinates*			Standard Deviation		
		Geodetic Latitude (Deg, Min, Sec)	East Longitude (Deg, Min, Sec)	Height (Meters)	Lat (Sec)	Lon (Sec)	Ht (M)
ARELAS	7907	-16 27 56.834	288 30 24.664	2476.53	0.049	0.040	0.83
1SHRAZ	9008	29 38 13.786	52 31 12.030	1566.93	0.116	0.139	4.39
1CURAC	9009	12 5 25.109	291 9 44.992	- 20.72	0.105	0.098	3.28
1VILDO	9011	-31 56 34.777	294 53 36.556	622.71	0.052	0.052	1.28
IMAUIO	9012	20 42 26.097	203 44 34.433	3040.82	0.054	0.045	1.22
HOPKIN	9021	31 41 2.993	249 7 18.799	2338.61	0.054	0.052	0.98
HOPLAS	7921	31 41 3.191	249 7 18.792	2338.00	0.054	0.052	0.98
AUSBAK	9023	-31 23 25.788	136 52 43.828	131.50	0.044	0.041	0.89
DODAIR	9025	36 0 20.012	139 11 32.248	877.29	0.112	0.132	3.46
DEZEIT	9028	8 44 51.256	38 57 33.837	1897.72	0.068	0.066	1.79
NATALB	9029	- 5 55 40.252	324 50 7.373	28.52	0.066	0.061	1.20
NATLAS	7929	- 5 55 40.252	324 50 7.373	29.14	0.066	0.061	1.20
COMRIV	9031	-45 53 12.463	292 23 9.539	186.85	0.062	0.079	1.98
AGASSI	9050	42 30 21.759	288 26 30.541	131.07	0.126	0.183	4.50
GREECE	9091	38 4 44.567	23 55 59.285	489.38	0.047	0.050	1.10
GRELAS	7930	38 4 42.473	23 55 57.668	496.42	0.047	0.050	1.10
COLDLK	9424	54 44 34.260	249 57 23.234	665.23	0.133	0.234	6.11
EDWAFB	9425	34 57 50.648	242 5 8.202	745.29	0.063	0.062	1.75
OSLONR	9426	60 12 39.545	10 45 4.869	593.98	0.187	0.360	9.74
JOHNST	9427	16 44 38.967	190 29 9.707	3.33	0.105	0.108	3.36
RIGALA	9431	56 56 55.437	24 3 32.470	11.11	0.050	0.094	1.92
UZHGOR	9432	48 38 1.831	22 17 55.471	216.12	0.050	0.071	1.79
HELSIK	9435	60 9 43.199	24 57 7.633	41.59	0.080	0.153	2.66

*a_e = 6378155.m, 1/f = 298.255

In order to utilize accurate survey ties between adjacent stations, the coordinates of certain stations were constrained to adjust in parallel. A list of the constrained stations is presented in Table 2. It is noted that no other constraints were employed in the solution since it was felt that the laser data could be used to reveal systematic differences due to the incompatibility of computation parameters such as scale which might otherwise be obscured. Also, the optical data provide a direct and absolute measure of latitude and longitude with proper modeling of UT1 and polar motion.

The goal of the authors was to produce a global solution with an accuracy of 5 meters in each coordinate. Our previous work employed the SAO 1969 Standard Earth Gravity Model which was found to be the best available at that time. Recently, Lerch, et al. at GSFC (1972) have produced a series of gravity models (GEM). Our global solution was computed using the GEM1 gravity model modified with the SAO 1969 resonant coefficients and repeated using the full SAO 1969 model. Generally, the results using GEM1 gave a more consistent set of recovered stations, a smaller RMS of fit to the data and the best overall results. It is the station solution with GEM1 and the SAO 12th, 13th and 14th order terms (resonant coefficients) which we have adopted for the GSFC '73 solution. In Section 3.5 a comparison of the results obtained with these two gravity models is presented.

A total of 65,000 optical observations and some 350 passes of laser data were used in our final simultaneous recovery. The NASA and CNES laser data were sampled leaving from 10 to 20 points per pass where possible. For those systems with slower data rates, all data available were used. The formal RMS of fit for this data set after station adjustment is presented in Table 3.

TABLE 2

STATIONS CONSTRAINED TO ADJUST IN PARALLEL

Mt. Hopkin, Arizona	7921-9021
Woomera, Australia	1024-9023
Carnarvon, Australia	7054-7079
Natal, Brazil	7929-9029
Jupiter, Florida	7071-7072
Haute Provence, France	89-7809-8015
Dionysis, Greece	7930-9091
Tokyo, Japan	9005-9025
Rosman, North Carolina	1037-1042
Olifantsfontein, Republic of South Africa	7902-9002
Arequipa, Peru	7907-9007
San Fernando, Spain	80-7804-9004

TABLE 3

RMS OF FIT TO THE DATA FOR STATION SOLUTION

	Number of Observations	RMS of Fit
Right Ascension	32122	1.62 seconds of arc
Declination	32301	1.54 seconds of arc
Laser Ranges	7043	4.6 meters

The number of observations for each station used in the solution is presented in Table 4. This fit to the data demonstrates that the optical data has a noise level well below 2 seconds of arc.

TABLE 4

NUMBER OF OBSERVATIONS BY STATION SELECTED
FOR THE GSFC '73 SOLUTION

STATION CODE NAME	NUMBER	NO. OF OBS.	STATION CODE NAME	NUMBER	NO. OF OBS.
1BPOIN	1021	918	GODLAS	7050	1812
1FTMYR	1022	3969	WALLAS	7052	178
1OOMER	1024	624	CRMLAS	7054	214
AUSBAK	9023	2938	1CARVN	7079	194
1SATAG	1028	1234	GMILAS	7060	1078
1MOJAV	1030	4266	1JUM24	7071	202
1JOBUR	1031	2236	1JUM40	7072	976
1NEWFL	1032	148	1SUDBR	7075	1350
1COLEG	1033	230	1JAMAC	7076	1412
1GFORK	1034	2194	DAKLAS	7820	326
1UNDAK	7034	893	DELFTH	8009	472
1WNKFL	1035	632	ZIMWLD	8010	1290
1ULASK	1036	558	MALVRN	8011	458
1ROSMN	1037	1832	HAUTEP	8015	802
1ROSMA	1042	1436	HAUTLS	89	503
1ORROL	1038	1186	HAULAS	7809	1233
1TANAN	1043	504	NICEFR	8019	516
1EDINB	7036	2364	MUDONI	8030	236
1COLBA	7037	4168	1ORGAN	9001	1844
1BERMD	7039	1568	1OLFAN	9002	2770
1PURIO	7040	1868	OILLAS	7902	346
1DENVR	7045	3078	1SPAIN	9004	3193
1CURAC	9009	310	SAFLAS	80;7804	939
1VILDO	9011	1318	1TOKYO	9005	58
1MAUIO	9012	1296	DODAIR	9025	84
HOPKIN	9021	854	1NATOL	9006	366
HOPLAS	7921	197	1QUIPA	9007	1506
DEZEIT	9028	398	ARELAS	7907	300
NATALB	9029	386	1SHRAZ	9008	174
NATLAS	7929	135	COMRIV	9031	508

TABLE 4 (Cont.)

STATION CODE NAME	NUMBER	NO. OF OBS.	STATION CODE NAME	NUMBER	NO. OF OBS.
AGASS1	9050	156	OSLONR	9426	28 *
[GREECE	9091	1322]	JOHNST	9427	166
[GRELAS	7930	60]	RIGALA	9431	660
COLDLK	9424	78	UZHGOR	9432	522
EDWAFB	9425	1026	HELSIK	9435	250

[ ] - Constrained Stations

* Only 1 pair of observations for each pass was precision reduced.

3.0 RESULTS

The final coordinate values are presented in Table 1. The formal error statistics for a solution of this nature based upon an analysis of the residuals are usually overly optimistic due to the fact that they do not consider the presence of unmodeled error sources. These formal statistics (table 1), however, do show a recovery to the 1 meter level in most cases. The goal of this section is to establish a reasonable accuracy estimate (ascribable to unmodeled error in our solution) through comparison with other independent solutions.

A brief description of the independent solutions used as a source of comparison for this paper is presented below:

- Solutions independent of the Earth's gravity field have been obtained by Mottinger (1969) of JPL (Deep Space Stations) and by Ryan (1972) of GSFC (Unified S-Band Stations) for precise distances from the Earth's spin axis and relative longitudes.

- Lunar laser data recorded at McDonald Observatory was analyzed by Williams, et al (1973) for the recovery of the distance from the Earth's spin axis.

- Narrow band VLBI techniques have been employed by Walls and Martin (1972) at GSFC to recover relative longitudes and spin axis distances for the S-Band tracking of the Lunar Excursion Module (LEM).

- Vincent and Marsh (1973) have produced gravimetric geoids encompassing most of the northern hemisphere and Australia providing a very accurate check on station heights.

- Geometric solutions based upon a combination of optical and laser data have been computed for Europe (Cazenave et al, 1971) and for North America (Reece et al, 1973). While the data sets for these solutions are subsets of our own, geometric procedures are not influenced by errors in satellite dynamics.

- VLBI techniques by Ramasastry et al (1973) at GSFC have yielded precise baselines across the United States.

- Ground based measurements such as surveys are used to establish a ground truth and an assessment of both systematic scale and local noise type errors.

- For dynamical satellite geodesy, the recently published solutions 1973 SAO Standard Earth by Gaposchkin at SAO (1973) and GSFC GEM4 (Lerch et al, 1972) provide intercomparisons for solutions using primarily optical and laser tracking.

The above list is not meant to be all inclusive but contains solutions which could be readily compared with our own. A wide variety of experimental techniques and instrumentation is sampled for these comparisons.

3.1 GSFC '73 COMPARISON WITH GEODETIC PARAMETERS RECOVERED AT JPL FOR THE DEEP SPACE NETWORK AND THE MCDONALD OBSERVATORY LUNAR LASER EXPERIMENT

In any data analysis effort, evaluation of the results is one of the most difficult and important tasks. In satellite geodesy, it is useful to compare the results of several investigators but in many cases the solutions are not truly independent. Fortunately the results of JPL for spin-axis distance and longitude differences are both highly accurate and are obtained independently of near Earth satellites.

As noted by Mottinger (1969), DSS data from interplanetary spacecraft do not yield a complete station position. The well-determined parameters are the distance of a station from the Earth's spin axis and the relative longitudes of the stations. The Earth-fixed Z component of the station position is poorly determined. Thus complete DSS positions rely on independent determinations.

In no case is an optical or laser station precisely contiguous with a DSS site. But in all cases except in Spain the stations are very close, so close that significant survey error can generally be regarded as unlikely.

The procedure used to infer optical coordinates from the DSN solutions follows. The local-to-center of mass shift for the DSN radar was calculated and then applied to the local coordinates of the nearby optical sites. In cases where two cameras are nearby and independently determined, both are presented. The resulting derived camera coordinates were then used to calculate spin-axis distances and longitude differences. A comparison of the spin-axis distances is given in Table 5 for the GSFC '73 and JPL LS25 solutions.

In previous optical solutions which used the SAO S.E. 1969 gravity model, we found little systematic difference in the recovered spin-axis distances for the cameras and nearby JPL radars (Marsh, Douglas, Klosko, 1971). This was probably due to two factors. First, the SAO station solution of 1969 contained some constraints from the JPL results and we held SAO information fixed initially in our previous work. Second, the semi-major axes of the orbital arcs were able to accommodate an error in GM.

In our recent work we included scale providing laser data. Also, no *a priori* station constraints were employed. These solutions produced spin axis distances which were systematically larger than those of JPL when using a value of GM = 3.986013×10^5 km^3/sec^2. However, when GM was changed to the more recent value of 3.986008×10^5 km^3/sec^2, Esposito and Wong, 1972) this disagreement was reduced.

The spin axis results obtained when using the value of GM = 3.986008×10^5 km^3/sec^2 indicated a scale difference of $+0.8 \times 10^{-6}$ for spin axis distances. The GM implied by this scale difference would be about 3.986000×10^5 km^3/sec^2. Allowing for this scale, the rms difference between JPL and GSFC '73 is 2.6 meters.

Analysis of laser range measurements to the lunar retro-reflectors recorded at McDonald Observatory, Ft. Davis, Texas by the lunar laser group (Williams, et.al., 1972) has yielded the distance of the observing site from the spin axis of the Earth with an accuracy of ± 3 meters. Table 6 presents a comparison of the lunar laser results and those obtained from recent optical/laser solutions including GSFC '73. When the .8 ppm scale factor as determined from the JPL comparison is subtracted from the GSFC '73 recovery, the agreement with the lunar laser is 30 cm.

TABLE 5

COMPARISON OF DISTANCES
FROM THE EARTH'S SPIN AXIS
FOR SITES INFERRED FROM
JPL DSN SOLUTION AND GSFC '73
INDEPENDENT SOLUTIONS

OPTICAL LOCATION	OPTICAL CODE NUMBER	JPL STATION $\Delta X, \Delta Y$* USED FOR INFERRED SOLUTION	SPIN AXIS DISTANCE (GSFC '73)-{JPL(LS25)] Meters	ppm	$\Delta r - (\overline{\Delta r}_{ppm} \times r)$
GOLDSTONE, CALIFORNIA	1030	DSN12	3.2m	.61	-1.0m
EDWARDS AFB, CALIFORNIA	9425	DSN12	6.3m	1.20	2.1m
WOOMERA, AUSTRALIA	9023	DSN41	8.1m	1.49	3.7m
JOHANNESBURG, REP.OF S.AFRICA	1031	DSN51	2.6m	.45	-2.0m
OLIFANTSFONTEIN,REP.OF S.AFRICA	9002	DSN51	1.3m	.23	-3.3m
ORRORAL, AUSTRALIA	1038	DSN42	7.0m	1.35	2.8m
SAN FERNANDO, SPAIN	9004	DSN61	1.6m	.31	-2.5m

$\overline{\Delta r}_{ppm} = 0.8$

*$\Delta X, \Delta Y$ is difference in surveyed X,Y and JPL recovered X,Y.

TABLE 6

SPIN AXIS DISTANCE FOR THE MCDONALD OBSERVATORY

GSFC '73	5492420.7m
GSFC '73*	5492416.3m
LUNAR LASER	5492416.0m
GSFC GEM4	5492418.3m
SAO '69	5492417.0m
SAO '73	5492413.4m

*Modified to account for scale difference of 0.8 ppm as determined from comparison of GSFC '73 and JPL.

Table 7 presents the longitude differences between JPL and GSFC '73 after removal of a longitude rotation of 0".27 (≈ 8 meters at the equator). It is noted that both the SAO 1969 and an earlier GSFC 1971 solution were rotated in longitude by about 0".75 with respect to JPL. In our present solutions using the SAO 1969 Standard Earth Gravity Model with no a priori information being supplied by SAO station recoveries, our results rotated into agreement with JPL longitude. With use of the GEM1 model, a rotation of 0".27 in longitude again appeared. When this 0".27 rotation is removed, the rms agreement in longitude is 2.6 meters. This rotation may be related to least squares accommodation of tesseral harmonic coefficient error.

TABLE 7

LONGITUDE DIFFERENCES
FOR SITES INFERRED FROM JPL DSN
SOLUTION AND GSFC '73
INDEPENDENT SOLUTIONS

OPTICAL LOCATION	OPTICAL CODE NUMBER	JPL STATION $\Delta\lambda$* USED FOR INFERRED SOLUTION	$\Delta\lambda - \overline{\Delta\lambda}$** LONGITUDE DIFFERENCE (GSFC '73) - [JPL(LS25)] SECONDS OF ARC	METERS
GOLDSTONE, CALIFORNIA	1030	DSN12	0".00	0.0
EDWARDS AFB, CALIFORNIA	9425	DSN12	0".11	-2.7
WOOMERA, AUSTRALIA	9023	DSN41	0".18	4.8
JOHANNESBURG, REP.OF S.AFRICA	1031	DSN51	0".02	0.6
OLIFANTSFONTEIN, REP.OF S.AFRICA	9002	DSN51	-0".03	-0.8
ORRORAL, AUSTRALIA	1038	DSN42	-0".13	-3.3
SAN FERNANDO, SPAIN	9004	DSN61	0".03	0.75

*$\Delta\lambda$ is difference in surveyed longitude and JPL recovered longitude.

**A mean longitude rotation of 0".27 has been applied to the GSFC values.

3.2 COMPARISONS WITH USB GEODETIC STATION LOCATIONS DETERMINED FROM LEM LUNAR SURFACE DATA AND MARINER 9

Martin and Walls with GSFC (Martin & Walls, 1972) have determined station positions for the Unified S-Band sites of the Spaceflight Tracking and Data Network (STDN) using metric data from the Lunar Excursion Module (LEM) while on the moon's surface. A set of positions were estimated in a combination solution reducing data from Apollo 14, 15 and 16. The JPL DSN stations were held fixed in this work and an analysis of the effects of all significant error sources indicated an accuracy of 10m for most stations for longitude and spin axis parameters. Frequency biases were the dominant errors except for those stations with hydrogen maser data - Bermuda, Merritt Island and Hawaii - for which residual refraction effects were the dominant errors. Narrow band VLBI was used for their recovery making the results virtually independent of the Earth's GM and errors in the lunar ephemeris.

Table 8 presents a comparison of the spin axis distances for the LEM solution and GSFC '73. The ΔX, ΔY and $\Delta\lambda$ parameters from the LEM recovered S-Band sites and the S-Band local surveys were used to derive nearby optical coordinates. Independent optical sites, in the case of Maryland - three such independent sites, are each transformed using the S-Band results. These inferred values are then compared with GSFC '73. Martin and Walls indicated in their published parameter uncertainties that their poorest determinations were at Guam and Carnarvon. The larger differences noted at Guam and Carnarvon are therefore not surprising. Merritt Island and Hawaii, which were indicated to have good recoveries, show differences with GSFC '73 which are unexpectedly large. As will be shown later, possible errors exist in the survey ties between the S-Band radar and camera sites.

TABLE 8

COMPARISON OF DISTANCES FROM THE EARTH'S SPIN AXIS FOR SITES INFERRED FROM NARROW BAND VLBI TRACKING OF THE LUNAR EXCURSION MODULE AND GSFC '73 INDEPENDENT SOLUTIONS

OPTICAL/LASER LOCATION	OPTICAL/LASER CODE NUMBER	S-BAND RADAR $\Delta X,\Delta Y$* USED FOR INFERRED SOLUTION	ΔSPIN AXIS DISTANCE (GSFC '73) - (LEM) METERS	
			Δr	$\Delta r-(\Delta\bar{r}_{ppm} xr)$
FORT MYERS, FLORIDA	1022	USB1 (MERRITT ISL.)	11.7m	7.1m
JUPITER, FLORIDA	7072	USB1 (MERRITT ISL.)	16.1m	11.6m
BLOSSOM POINT, MARYLAND	1021	USB16 (GSFC)	- 0.7m	- 4.7m
GSFC, MARYLAND	7050**	USB16 (GSFC)	- 6.3m	-10.3m
WALLOPS ISLAND, VIRGINIA	7052**	USB16 (GSFC)	-11.5m	-15.5m
BERMUDA	7039	USB3 (BERMUDA)	1.1m	- 3.2m
CARNARVON, AUSTRALIA	7054**	USB8 (CARNARVON)	12.1m	7.5m
GUAM	7060**	USB9 (GUAM)	10.9m	5.9m
MAUI, HAWAII	9012	USB11 (KAUAI, HAWAII)	-13.5m	-18.3m
EDINBURG, TEXAS	7036	USB14 (CORPUS CHRISTI)	- 4.5m	9.1m

*$\Delta X,\Delta Y$ is difference in survey X,Y and recovered S-Band X,Y.

**NASA lasers

$\Delta\bar{r}$ is the scale of .8 ppm determined from GSFC/JPL comparisons.

Table 9 presents a comparison of the longitudes derived from the LEM solutions with those of GSFC '73. Again, Hawaii shows a large disagreement. The agreement elsewhere is very good with an RMS of 5.0 meters.

Ryan at GSFC (Ryan, 1972) used data recorded during Mariner-Mars 1971 Unified S-Band Tracking and Calibration Experiment by the S-Band sites of the STDN to recover spin-axis distances and relative longitudes. The Deep Space Network supported this experiment. The DSN locations were held unadjusted in Ryan's work at the LS-25 values. Using 3-way USB doppler data with corresponding 2-way DSN doppler data, Ryan recovered values using least squares regression analysis. Ryan places 15m as an upper bound for error in his work.

Table 10 presents a comparison of spin axis distances for Ryan and GSFC '73. Contrary to Martin and Walls, Ryan indicates that he had good spin-axis recoveries at Guam and Carnarvon. Here we find good agreement with GSFC '73. Elsewhere the agreement with Ryan is only slightly different than that of the LEM solution with Merritt Island and Hawaii continuing to show large differences.

Table 11 presents a comparison with the Mariner 9 solution for longitude. While Hawaii and Merritt Island show large disagreement, the Mariner 9 solution for ETC (GSFC) also seems to be inconsistent with both the LEM and the GSFC '73 recovery. Ryan indicated that ETC was a known poor determination.

TABLE 9

LONGITUDE DIFFERENCES
FOR SITES INFERRED FROM NARROW BAND
VLBI TRACKING OF THE LUNAR
EXCURSION MODULE AND GSFC '73
INDEPENDENT SOLUTIONS

OPTICAL/LASER LOCATIONS	OPTICAL/LASER CODE NUMBER	S-BAND RADAR Δλ* USED FOR INFERRED SOLUTION	LONGITUDE DIFFERENCE (GSFC '73)•- (LEM) SECONDS OF ARC	METERS
FORT MYERS, FLORIDA	1022	USB1 (MERRITT ISL.)	0".00	0.0m
JUPITER, FLORIDA	7072	USB1 (MERRITT ISL.)	0".13	3.6m
BLOSSOM POINT, MARYLAND	1021	USB16 (GSFC)	-0".32	-7.7m
GSFC, MARYLAND	7050**	USB16 (GSFC)	-0".22	-5.7m
WALLOPS ISLAND, VIRGINIA	7052**	USB16 (GSFC)	0".04	1.0m
BERMUDA	7039	USB3 (BERMUDA)	0".02	0.5m
CARNARVON, AUSTRALIA	7054**	USB8 (CARNARVON)	0".13	3.7m
GUAM	7060**	USB9 (GUAM)	0".33	9.9m
MAUI, HAWAII	9012	USB11 (KAUAI, HAWAII)	0".51	14.7m
EDINBURG, TEXAS	7036	USB14 (CORPUS CHRISTI)	-0".12	-3.3m

*Δλ is difference in surveyed longitude and LEM recovered longitude

**NASA laser

•The S-Band solution is consistent with JPL. The GSFC '73/JPL rotation of 0".27 was therefore applied in this comparison.

TABLE 10

COMPARISONS OF DISTANCES
FROM THE EARTH'S SPIN AXIS FOR
SITES INFERRED FROM THE DYNAMICAL S-BAND
SOLUTION USING DATA FROM MARINER 9
AND THE GSFC '73 INDEPENDENT SOLUTIONS

OPTICAL/LASER LOCATION	OPTICAL/LASER CODE NUMBER	S-BAND RADAR $\Delta X,\Delta Y$* USED FOR INFERRED SOLUTION	SPIN AXIS DISTANCE (GSFC '73) - (RYAN) METERS	
			Δr	$\Delta r-(\overline{\Delta r}^{*} \times_{ppm} r)$
FORT MYERS, FLORIDA	1022	USB1 (MERRITT ISL.)	11.3	6.7m
JUPITER, FLORIDA	7072	USB1 (MERRITT ISL.)	15.9	11.4m
BLOSSOM POINT, MARYLAND	1021	USB16 (GSFC)	9.4	5.4m
GSFC, MARYLAND	7050**	USB16 (GSFC)	3.8	- 0.2m
WALLOPS ISLAND, VIRGINIA	7052**	USB16 (GSFC)	-1.0	- 5.0m
BERMUDA	7039	USB3 (BERMUDA)	1.9	- 2.4m
CARNARVON, AUSTRALIA	7054**	USB8 (CARNARVON)	3.8	- 0.8m
GUAM	7060**	USB9 (GUAM)	6.5	1.5m
MAUI, HAWAII	9012	USB11 (KAUAI, HAWAII)	-16.3	-21.0m
EDINBURG, TEXAS	7036	USB14 (CORPUS CHRISTI)	8.9	4.3m

*$\Delta X,\Delta Y$ is difference in survey X,Y and Mariner 9 recovered S-Band X,Y.

**NASA lasers

TABLE 11

LONGITUDE DIFFERENCE
FOR SITES INFERRED FROM THE DYNAMICAL
S-BAND SOLUTION USING DATA FROM MARINER 9
AND THE GSFC '73 INDEPENDENT SOLUTIONS

OPTICAL/LASER LOCATION	OPTICAL/LASER CODE NUMBER	S-BAND RADAR Δλ* USED FOR INFERRED SOLUTION	LONGITUDE DIFFERENCE (GSFC '73)•- (RYAN) SECONDS OF ARC	METERS
FORT MYERS, FLORIDA	1022	USB1 (MERRITT ISL.)	0".34	9.5
JUPITER, FLORIDA	7072	USB1 (MERRITT ISL.)	0".47	13.0
BLOSSOM POINT, MARYLAND	1021	USB16 (GSFC)	0".41	10.0
GSFC, MARYLAND	7050**	USB16 (GSFC)	0".51	12.3
WALLOPS ISLAND, VIRGINIA	7052**	USB16 (GSFC)	0".77	18.8
BERMUDA	7039	USB3 (BERMUDA)	0".02	0.5
CARNARVON, AUSTRALIA	7054**	USB8 (CARNARVON)	0".17	4.8
GUAM	7060**	USB9 (GUAM)	0".21	6.3
MAUI, HAWAII	9012	USB11 (KAUAI, HAWAII)	0".57	16.4
EDINBURG, TEXAS	7036	USB14 (CORPUS CHRISTI)	0".05	1.4

*Δλ is difference in surveyed longitude and Mariner 9 recovered longitude.

**NASA laser

•The S-Band solution is consistent with JPL. The GSFC '73/JPL rotation of 0".27 was therefore applied in this comparison.

Table 12 presents four optical/laser solutions compared with these two S-Band solutions for spin-axis distance at Hawaii and Merritt Island. Note that while the two independent S-Band solutions agree very well, so too, do the optical solutions agree! In Florida the optical stations are on the mainland while the USB station is off the coast. In the case of Hawaii, the S-Band and Baker-Nunn camera are located on different islands. The close agreement for solutions measuring their respective instruments seemingly indicates questionable survey ties between the S-Band radars and cameras at these locations.

TABLE 12

COMPARISON OF DISTANCES
FROM THE EARTH'S SPIN AXIS
FOR FLORIDA AND HAWAII

		INFERRED SPIN AXIS DISTANCE* UNIFIED S-BAND SOLUTIONS		RECOVERED SPIN AXIS DISTANCE* OPTICAL/LASER SOLUTION			
LOCATION	CODE NUMBER	MARTIN (LEM)	RYAN (MARINER 9)	GSFC '73	GEM4 '72	SAO '69	SAO '73
FLORIDA	7072	820.5	820.7	836.6	832.4		
	1022	410.7	411.1	422.4	425.5		
	9010	826.0	826.2		845.6	842.4	833.2
HAWAII	9012	478.0	480.8	464.5	464.6	457.7	470.1

*Last three digits of values in meters.

3.3 EVALUATION OF RADIAL POSITIONS

The relative longitude and spin axis distance comparisons presented in the preceding section provide an excellent means of assessing the precision of the geocentric X and Y coordinate values of the solution. This precision has been shown to be a very few meters. These comparisons are insensitive to the Z values however. Systematic errors as large as five meters can occur in Z due to errors in zonal harmonics (Anderle 1973). Other errors are also present, primarily due to uncertainties in modeling tesseral and sectorial harmonics. Errors in Z will be propagated into errors in the heights above the reference ellipsoid for stations not on the equator.

Gravimetric geoids have been used to evaluate the radial coordinates of our solution. On a global basis we have used the geoid corresponding to the GSFC GEM-4 gravity field (Marsh et al, 1973). Comparisons of this global geoid with detailed gravimetric geoids indicated that the accuracy is generally on the order of five to ten meters.

In the areas of North America, Europe and Australia, the detailed gravimetric geoid (Vincent and Marsh, 1973) based upon a combination of surface gravity data and satellite data has been used. The accuracy of the detailed geoid has been assessed as about 2 meters.

Figure 2 presents a plot of Δh where

$$\Delta h = (h_{el} - h_{msl}) - N$$

versus station latitude where:

h_{el} is the height of the station above the reference ellipsoid

h_{msl} is the height of the station above mean sea level obtained from survey data

and

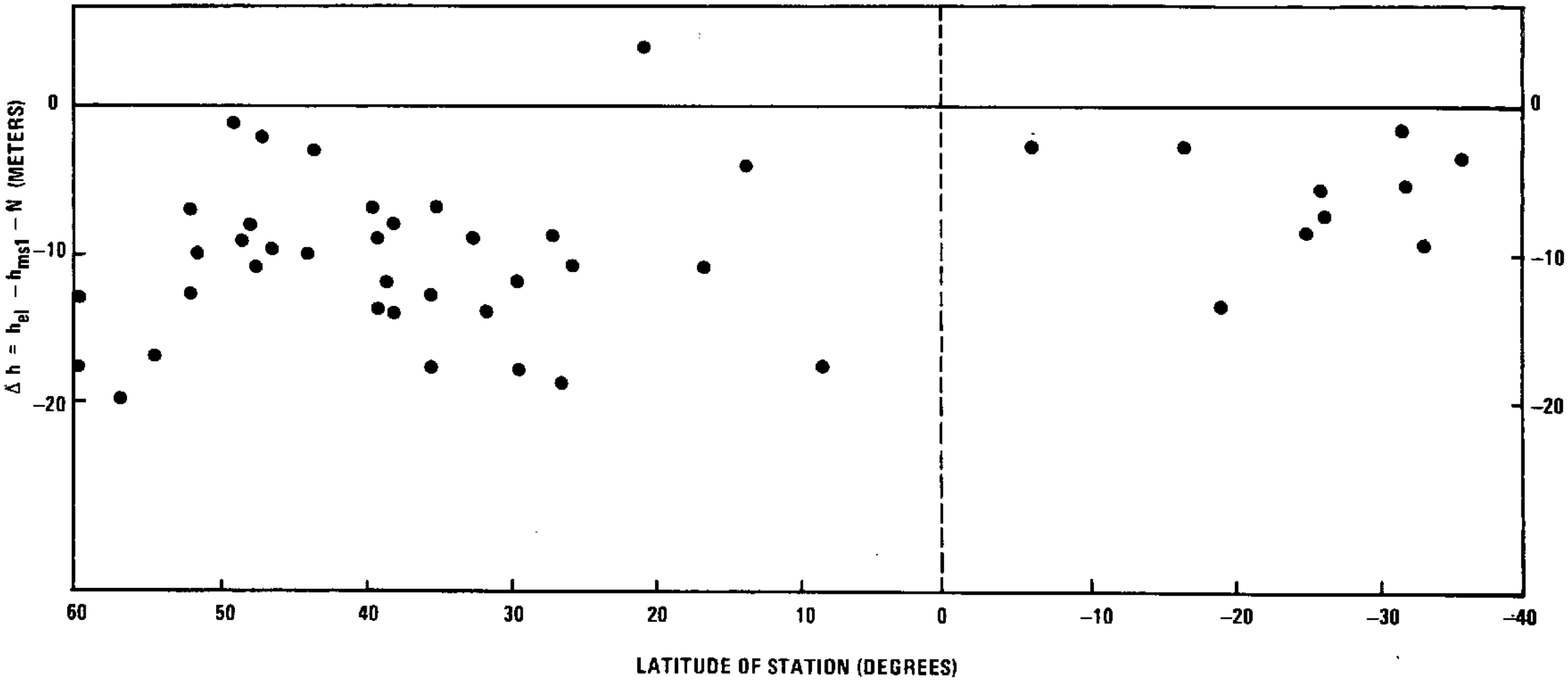
N represents the GEM-4 global geoid heights.

Thus the differences presented in the Figure 2 represent the sum of errors in the dynamically determined height, the survey height above mean sea level and the satellite geoid height. The RMS difference for this comparison is 5.6 meters, after removal of a systematic difference. This systematic difference is due to the difference in semi-major axes used for the geoid heights (6378142m) and the reference figure for the recovered station coordinates (6378155m). This result agrees well with Mueller (1973) and Lerch (1972) who both indicated that a reference ellipsoid of 6378155m is too large by at least 10m. This plot indicates no significant slope in the residuals as a function of latitude which means that displacement of the origin of the coordinate system along the Z axis must be less than a few meters.

Figure 3 presents a comparison of the station heights in North America, Europe and Australia versus the detailed gravimetric geoid heights. The overall RMS difference for these three areas is 4.1 meters, reflecting the increased accuracy of the detailed geoid over the global satellite geoid. The ellipsoid implied by this more accurate comparison would have a semi-major axis of 6378142$\pm$2m. It is also important to note that no significant scale differences are indicated for these areas. This indicates that a small value as an upper bound exists in the systematic error in MSL definition for these three continents.

Both noise and systematic errors in the Z coordinates are assessed to be less than 4m RMS for the GSFC '73 solution.

FIGURE 2. GEOID HEIGHT COMPARISON BETWEEN GSFC '73 AND THE GEM4 SATELLITE GEOID

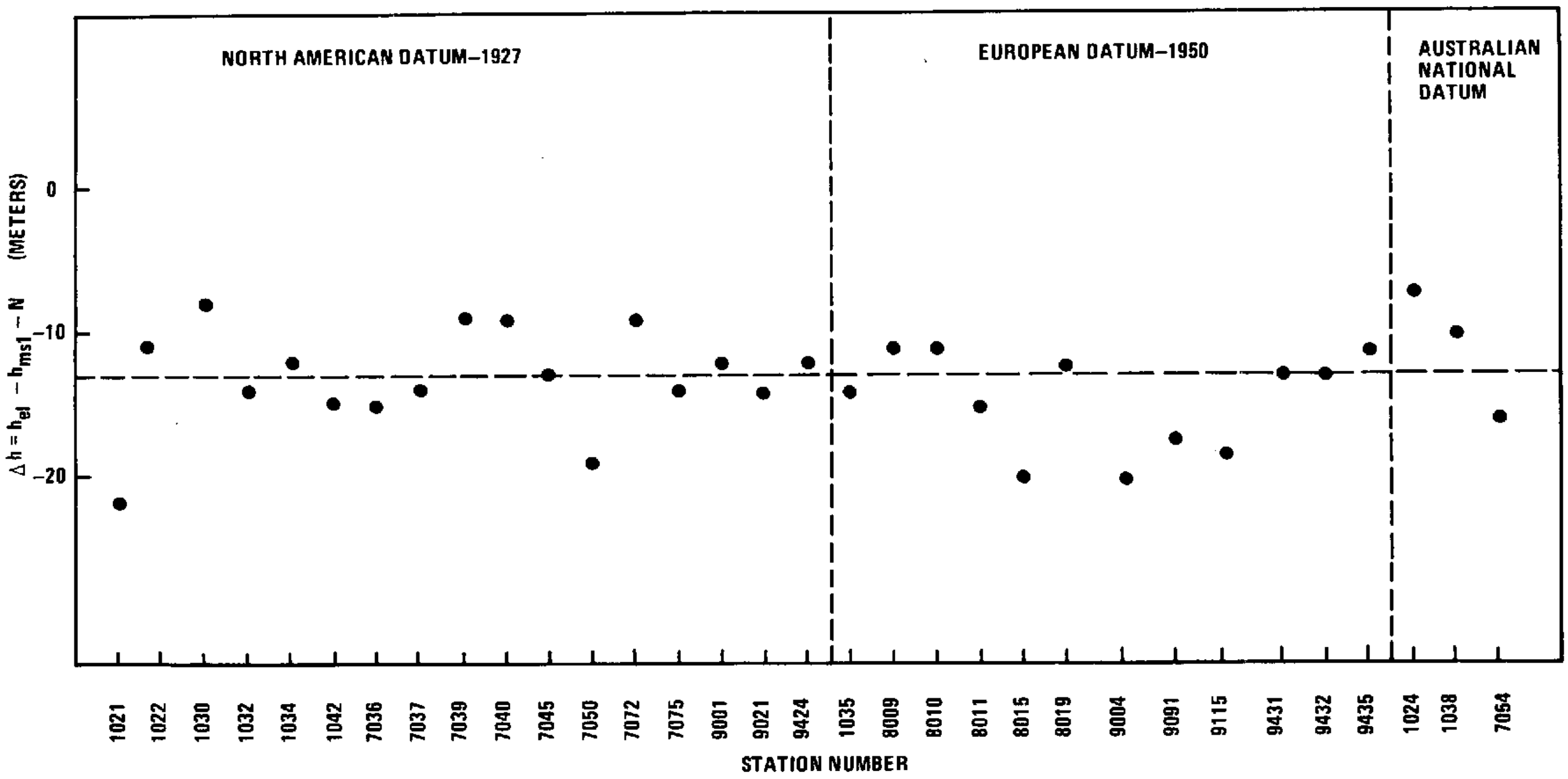


h_{el} = Dynamically determined height of station above ellipsoid (a_e = 6378155m, 1/f = 298.255)

h_{ms1} = Survey height of station above mean sea level.

N = Geoid height – GEM-4 Global Geoid.

FIGURE 3. GEOID HEIGHT COMPARISON FOR GSFC '73 AND THE GRAVIMETRIC GEOID



h_{el} = Dynamically determined height of station above ellipsoid (a_e = 6378155m, 1/f = 298.255)

h_{msl} = Survey height of station above mean sea level.

N = Detailed gravimetric geoid height (Vincent and Marsh, 1973)

3.4 INTERCOMPARISON OF CHORD DISTANCES ON THE NORTH AMERICAN AND EUROPEAN DATUMS

This section presents a chord distance comparison of the GSFC '73 solution with; the geometric satellite solutions of Reece et al, 1973 for North America, Cazenave et al, 1972, for Europe and the VLBI solution of Ramasastry et al, 1973.

Simultaneous observations of the GEOS-1 and II flashing lamps taken by the NASA MOTS and SPEOPT cameras were used by Reece et al to recover relative coordinates of thirteen sites on the North American Datum. Scale for this solution was provided by processing laser data from Greenbelt and Wallops Island simultaneously with the optical data. The GSFC '73 solution also provided coordinates for these stations. Figure 4 presents a histogram of the chord distance agreement between the geometric and dynamic solutions. Of the 77 common chords, 63 agree to 5 meters or better.

A seven parameter transformation (3-translation, 3-orientation, 1-scale) was performed to relate the respective GSFC '73 and Reece station sets to a common coordinate system. The overall scale difference recovered was -0.17 ppm. This agreement is very good considering the different techniques employed. Table 13 presents the residuals in X,Y,Z by station between the geometric and dynamic solutions from this orientation solution.

FIGURE 4.
HISTOGRAM OF NORTH AMERICAN CHORD AGREEMENT BETWEEN THE REECE GEOMETRIC AND GSFC '73 DYNAMIC SOLUTIONS

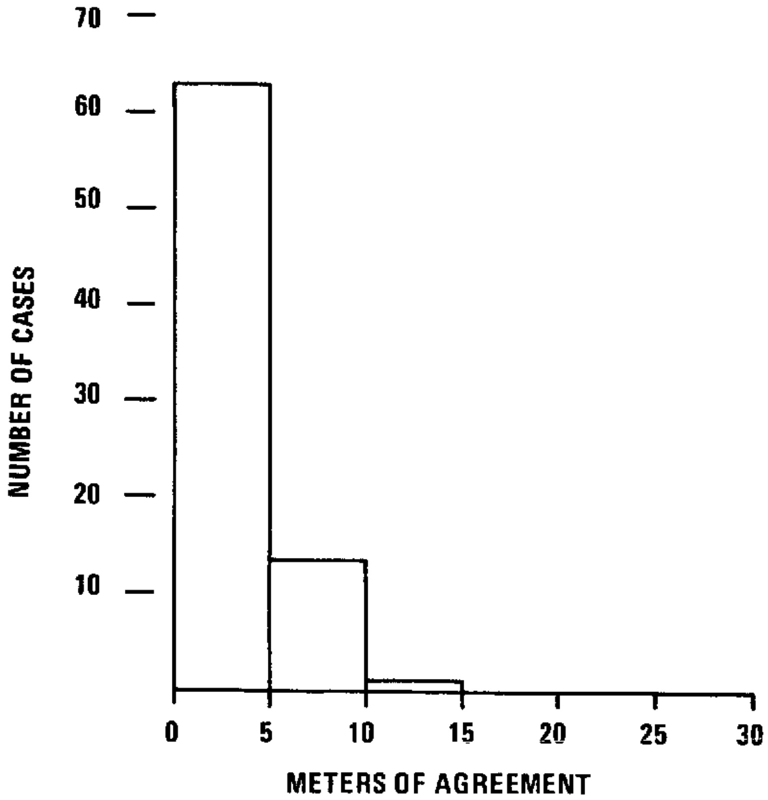


TABLE 13

RESIDUALS BY STATION
IN METERS BETWEEN THE GEOMETRICAL
SOLUTION OF REECE AND GSFC '73

STATION NAME	STATION NUMBER	X	Y	Z
1MOJAV	1030	0.4	-0.7	1.3
1BPOIN	1021	-0.6	-0.3	-8.5
1EDINB	7036	-0.9	2.7	0.0
1COLBA	7037	1.6	0.7	-0.3
1BERMD	7039	-3.7	2.1	4.2
1PURIO	7040	-1.2	-2.3	4.4
1DENVR	7045	-1.2	-1.2	2.8
1SUDBR	7075	-2.0	2.1	2.3
1JAMAC	7076	2.0	0.9	-2.5
1FTMYR	1022	1.6	0.9	0.2
1JUM40	7072	1.0	-4.4	-6.7
1GFORK	1034	0.8	2.3	1.0
1ROSMA	1042	2.1	-2.8	1.8
RMS of Fit		1.7m	2.1m	3.7m

Wideband noise signals from quasars have been analyzed by Ramasastry et. al. (1973) using Very Long Baseline Interferometric (VLBI) techniques to provide a baseline from the Rosman, North Carolina 85 foot antenna to the Goldstone, California 40 foot antenna with a standard deviation of 14 cm. Local survey ties between the cameras and radar antennas at the respective stations have been used to infer a baseline from the GSFC '73 dynamical solution. The difference between the VLBI and dynamically derived baseline as shown in Table 14 is 70cm.

At Centre National d'Etudes Spatiales (CNES) in France Cazenave and her associates (1971) used purely geometric techniques with optical and laser data to recover the chord distances between San Fernando, Spain and eight other sites in Europe.

Table 15 compares the chord lengths obtained from GSFC '73 with the geometric solution of CNES. The agreement between GSFC and CNES is good, 6 of the 8 chords agreeing to 4.5 meters. The disagreement of the chord to Greece may be due to the fact that this station is on the periphery of the geometric net and therefore is constrained in only limited directions in the CNES solution. However, the mean difference between the CNES and GSFC '73 results, including Greece, is still only a few meters. When Greece is eliminated the mean scale difference between GSFC '73 and CNES is 0.3 ppm.

The GSFC '73 dynamical solution when compared with these independent geometrical solutions of Reece and Cazenave and the VLBI solution of Ramasastry indicates agreement to better than 5 meters in almost all cases. This is consistent with our error analysis which indicated that the recovered coordinates for GSFC '73 on North America and Europe are accurate to 3m (1σ) in each coordinate.

TABLE 14

Agreement With Survey for the Chord from Rosman, N.C. and Goldstone, California Satellite-Survey

VLBI (Ramasastry)	=	7.4m
GSFC 1973	=	8.1m
GSFC 1973 - VLBI	=	0.7m

TABLE 15

COMPARISON OF CHORD DISTANCES FROM
STATION 9004 (SAN FERNANDO, SPAIN)
AND THE EUROPEAN DATUM OF 1950*

STATION	NUMBER	SURVEY-SAT (m)		SURVEY-SAT (ppm)		GSFC - CNES	
		CNES	GSFC '73	CNES	GSFC '73	(m)	(ppm)
UZHGOR	9432	-20.5	-22.5	-7.7	-8.5	-2.0	-0.8
RIGALA	9431	-21.5	-14.9	-6.8	-4.7	6.6	2.1
GREECE	9091	-26.1	-12.6	-9.8	-4.7	13.3	5.1
NICEFR	8019	-14.7	-12.7	-10.5	-9.1	2.0	1.4
HAUTEP	8015	-16.8	-17.9	-12.9	-13.7	-1.1	-0.8
MALVRN	8011	-12.2	- 8.3	-6.9	- 4.7	3.9	2.2
ZIMWLD	8010	-17.6	-19.8	-10.8	-12.2	-2.3	-1.4
1DELFT	8009	-6.5	-10.8	-3.3	- 5.6	-4.3	-2.3

*The local survey values are based upon the 1971 Bomford geoid.

3.5 COMPARISONS WITH THE GLOBAL STATION SOLUTIONS OF SAO 1973 AND GEM 4

In the last year, two major solutions for global laser and camera coordinates have been published. Lerch et al (1972) at GSFC published a set of station coordinates simultaneously recovered with the GEM 4 gravity model. Gaposchkin at SAO (Gaposchkin, 1973) solved for a global set of station coordinates in an iterative process along with the recent SAO Standard Earth III gravity model. This section will assess the level of agreement between our GSFC '73 determination and these values.

The accuracy of global station coordinate values derived using dynamical techniques varies. In a least squares determination of orbital position larger errors normally occur over areas with limited or no tracking for near earth satellites. Therefore, the isolated stations with limited data sets result in the poorest determinations. In order to more realistically assess the difference between the GSFC '73 solution and the GEM 4 and SAO '73 values, seven stations with known larger position uncertainties were omitted from the analysis.

The GEM-4 solution used the value of GM = $3.986013 \times 10^5\ km^3/sec^2$. In order to compare these values with our own, an orientation solution of seven parameters was computed for 34 independent common stations. Table 16 presents the results from this solution. The scale difference of .46 ppm is very close to the expected value since the GSFC '73 solution used a value of GM = $3.986008 \times 10^5\ km^3/sec^2$. The translation parameters, ΔX, ΔY, and ΔZ, are 50 cm of less in each case. A rotation of about 0.3 arc seconds in longitude is noted. The RMS of fit for the 34 stations as shown in Table 16 indicates agreement to better than 5 meters between GSFC '73 and GEM 4. This agreement is especially significant in that GEM 4 used a different technique than GSFC '73 by solving for a gravity

TABLE 16

ORIENTATION SOLUTION
BETWEEN THE GLOBAL GEOCENTRIC
SOLUTIONS OF GEM4 AND GSFC'73
FOR 34 COMMON STATIONS

ΔX meters	ΔY meters	ΔZ meters	Δℓ ppm	omega arc sec	psi arc sec	epsilon arc sec
-0.5±0.2	-0.1±0.2	0.5±0.2	0.45 ±.03	0"26 ±.01	0"11 ±.01	0"01 ±.01

CORRELATION COEFFICIENTS

	ΔX	ΔY	ΔZ	Δℓ	omega	psi
ΔY	.012					
ΔZ	-.019	.057				
Δℓ	-.140	.415	-.242			
omega	.426	.194	.073	$.462\text{X}10^{-16}$		
psi	.236	-.079	-.259	$-.186\text{X}10^{-18}$	-.216	
epsilon	.015	-.303	-.495	$-.124\text{X}10^{-15}$	-.067	.141

RMS of Fit	X	Y	Z
	3.8 meters	4.3 meters	3.6 meters

model complete with zonals simultaneously with the station coordinates and a different gravity model was employed (GEM 1 vs. GEM 4).

A similiar analysis was performed using 24 common stations of GSFC '73 and SAO '73. Here the differences were larger. The RMS of fit for the 24 stations was 8.9, 10.5, and 13.4 meters in X, Y, and Z respectively. A comparison of the SAO '73 solution with respect to geoid height, indicated a 25 meter discrepancy between the recovered heights in Europe and those of North America and Australia. This discrepancy largely accounts for the larger differences between GSFC '73 and SAO '73.

A comparison using this method was also performed to assess the effect of gravity model error on our solution. A seven parameter orientation solution was performed for 50 independent stations determined using the GEM 1 and Standard Earth 1969 Gravity Model. Table 17 presents the parameter values derived for this orientation solution. This comparison indicates a longitude rotation of 0.35 arc seconds as was discussed in Section 3.1. This method also would reveal other systematic discrepancies between the different gravity model solutions. The scale recovered in this transformation solution was a very small -.06 ppm. Except for the rotation in longitude (omega), systematic difference between the solutions were less than 3 meters. The RMS of fit between these two sets of 50 stations was 3.8, 2.8, and 3.4 meters in X, Y, and Z respectively.

Table 18 presents final uncertainty estimates for our GSFC '73 recovered stations based upon error analyses and comparisons performed in this section. For most sites, an accuracy of 5m (1σ) in each coordinate is quoted.

TABLE 17

AN ORIENTATION
SOLUTION BETWEEN
GSFC'73 SOLUTIONS
USING DIFFERENT GRAVITY
MODELS*

ΔX	ΔY	ΔZ	$\Delta \ell$ ppm	omega	psi	epsilon
$3.0 \pm .2$	$-1.8 \pm .2$	$1.36 \pm .2$	$-.06 \pm .02$	$-0''.35 \pm .01$	$0''.07 \pm .01$	$0''.09 \pm .07$

*the gravity models used were the S.E 1969 and GEM1 models.

TABLE 18

ESTIMATED UNCERTAINTY
IN THE GSFC '73 STATION
SOLUTION

STATIONS	NUMBER	UNCERTAINTY IN METERS IN EACH COORDINATE
1021	1BPOIN	5
1022	1FTMYR	3
1028	1SATAG	5
1030	1MOJAV	3
1031	1JOBUR	3
1032	1NEWFL	7
1033	1COLEG	10
1034	1GFORK	3
1035	1WNKFL	3
1036	1ULASK	5
1038	1ORROL	5
1042	1ROSMA	3
1043	1TANAN	5
7036	1EDINB	3
7037	1COLBA	3
7039	1BERMD	3
7040	1PURIO	3
7045	1DENVR	3
7050	GODLAS	3
7052	WALLAS	7
7054	CRMLAS	5
7060	GMILAS	7
7072	1JUM4O	3
7075	1SUDBR	3
7076	1JAMAC	3
7820	DAKLAS	10
8009	DELFTH	3
8010	ZIMWLD	3
8011	MALVRN	5
8015	HAUTEP	3
8019	NICEFR	3
8030	MUDONI	5
9001	1ORGAN	3
9002	1OLFAN	3
9004	1SPAIN	3
9005	1TOKYO	7
9006	1NATOL	7
9007	1QUIPA	3
9008	1SHRAZ	10
9009	1CURAC	7
9011	1VILDO	3
9012	1MAUIO	3

TABLE 18 (CONT.)

STATIONS	NUMBER	UNCERTAINTY IN METERS IN EACH COORDINATE
9021	HOPKIN	3
9023	AUSBAK	3
9028	DEZEIT	5
9029	NATALB	5
9031	COMRIV	5
9050	AGASSI	7
9091	GREECE	3
9424	COLDLK	10
9425	EDWAFB	3
9426	OSLONR	10
9427	JOHNST	10
9431	RIGALA	3
9432	UZHGOR	3
9435	HELSIK	5

4.0 THE RELATION OF MAJOR GEODETIC DATUMS TO A GEOCENTRIC REFERENCE SYSTEM

The relation of the North American Datum 1927, the European Datum-1950, the Provisional South American Datum-1969, and the Australian Geodetic Datum to the geocentric reference system of the GSFC '73 solution has been established through the derivation of values for seven transformation parameters (three translation, three rotation and scale) for each datum. For the Arc Datum, the two available stations have been used to derive the translation of the datum.

Survey coordinates were obtained primarily from the "NASA Directory of Observation Station Locations" (1971). The survey coordinates for the optical and laser stations located at Haute Provence, France, were obtained in a private communication with Brachet, 1973, of CNES.

4.1 THE NORTH AMERICAN DATUM-1927

A total of 14 stations, 12 continental and the island stations of Jamacia and Puerto Rico have been used to establish the orientation of the North American Datum 1927 (NAD) to a geocentric reference system established by our GSFC '73 dynamical solution. Table 19 presents values for the seven orientation parameters, their correlation coefficients, associative residuals in X,Y and Z, and chord length differences. The scale difference indicates that the North American Datum is smaller than the geocentric solution by 0.9 ± 0.2 ppm. This value is in good agreement with the 0.8 ppm derived from the GSFC '73 JPL spin axis distance comparison. The residuals in X,Y, and Z have RMS values of 3.4, 2.6 and 3.8 meters respectively.

TABLE 19

THE ORIENTATION AND CHORD LENGTH AGREEMENT FOR THE NORTH AMERICAN 1927 DATUM WITH GSFC '73

TRANSFORMATION PARAMETERS FOR THE NORTH AMERICAN 1927 DATUM AND THE GEOCENTRIC REFERENCE SYSTEM

ΔX	ΔY	ΔZ	$\Delta \ell$	OMEGA	PSI	EPSILON
-42.7 ± 1	161.6 ± 1	179.0 ± 2	.9 ppm	–1.″1	–.″2	–.″05
			$\pm .2$	$\pm .04$	$\pm .04$	$\pm .07$

CHORD LENGTH AGREEMENT BETWEEN THE NORTH AMERICAN 1927 DATUM AND GSFC '73 (SATELLITE–SURVEY) IN METERS

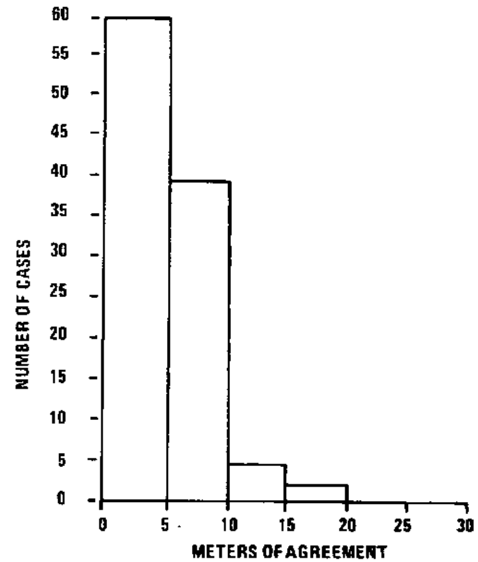
	1022	9021	9001	7076	7075	7072	7050	7045	7040	7037	7036	7034	1042	1030
9021	7.4													
9001	2.7	4.3												
7076	0.5	1.8	–2.7											
7075	7.4	8.9	8.9	10.8										
7072	–3.6	9.1	4.9	–5.6	16.1									
7050	5.6	0.8	0.7	5.3	–2.4	15.2								
7045	4.3	8.2	10.0	2.3	0.9	8.6	–5.0							
7040	–7.5	–1.6	–5.4	–2.6	5.2	–10.1	7.6	–2.6						
7037	–0.9	4.7	2.6	–1.1	7.5	5.7	–3.8	0.7	–5.3					
7036	6.8	1.3	–5.0	1.7	9.1	6.1	4.5	3.6	–2.1	–0.5				
7034	0.9	7.0	8.0	1.5	–3.1	8.0	–9.3	–1.1	–3.3	2.9	2.6			
1042	–4.0	6.6	3.5	–1.5	11.2	4.5	3.6	3.3	–6.9	1.8	2.8	3.1		
1030	8.7	2.0	7.7	4.0	7.9	11.3	2.0	7.4	0.6	6.2	3.3	7.7	8.1	
1021	–7.8	–1.2	–3.6	–1.2	9.2	1.8	13.0	–5.2	–3.5	–5.2	–4.1	–3.2	–6.2	0.4

CORRELATION COEFFICIENTS

	ΔX	ΔY	ΔZ	$\Delta \ell$	OMEGA	PSI
ΔY	.209					
ΔZ	.248	.453				
$\Delta \ell$	.007	.579	–.337			
OMEGA	.849	.184	.224	$-.37 \times 10^{-15}$		
PSI	.624	.131	.160	$-.24 \times 10^{-15}$	.170	
EPSILON	–.266	–.795	–.929	$.17 \times 10^{-14}$	–.241	–.166

RESIDUALS BY STATION FOR NORTH AMERICAN 1927 DATUM ORIENTATION SOLUTION

STATION NAME	NUMBER	RESIDUALS IN METERS X	Y	Z
HOPKIN	9021	1.4	–2.2	3.0
1ORGAN	9001	–1.3	4.2	3.7
1SUBBR	7075	–0.6	–4.2	–6.1
1JUM40	7072	–3.6	3.9	5.1
GODLAS	7050	4.2	–4.7	–7.1
1DENVR	7045	–3.0	–1.6	–3.6
1PURIO	7040	6.8	0.5	–0.6
1COLBA	7037	–1.6	1.9	2.0
1EDINB	7036	1.1	1.2	–1.5
1UNDAK/1GFORK	7034	–3.9	1.7	–1.6
1ROSMA	1042	–2.6	1.0	2.7
1MOJAV	1030	2.2	–1.6	0.7
1BPOIN	1021	5.0	1.0	5.3
1FTMYR	1022	–4.2	–1.0	–2.1
RMS OF FIT		3.4 m	2.6 m	3.8 m



HISTOGRAM OF CHORD AGREEMENT BETWEEN NORTH AMERICAN 1927 DATUM AND GSFC '73

4.2 THE EUROPEAN DATUM-1950

Nine stations have been used in relating the European Datum to this global reference system. Table 20 presents information similar to that presented in Table 19 for the North American Datum. The comparison of our solution with that of CNES indicated a mean scale difference of 0.3 ppm for chords to San Fernando, Spain. The overall scale difference derived in the seven parameter solution was 5.0 $\pm$ 0.4 ppm. This large scale difference is primarily attributed to the fact that the European Datum contains a systematic scale error due to the unavailability of the geoid heights throughout this system at the time of its reduction in 1950 (Bomford, 1971). The values used for the surveyed chords in the chord length comparison and histogram in Table 20 have been modified to account for this error. After correction, 23 out of a total of 36 chords show differences of 5 meters or less.

The residuals in X,Y,Z have RMS values of 3.0, 3.6 and 4.3 meters, respectively.

4.3 THE PROVISIONAL SOUTH AMERICAN DATUM-1969

Five stations tied to the Provisional South American Datum were used in the study of this datum. A scale difference of -1.8 $\pm$ 0.2 ppm was derived for this datum. Curacao was omitted from the analysis since chords from this station to Natal, Brazil and Arequipa, Peru were different from survey values by -16.1 meters and 21.7 meters, respectively. However, the differences between our values and those of GEM-4 and SAO '69 were on the order of a few meters. The residuals in X,Y,Z for this datum

TABLE 20

THE ORIENTATION AND CHORD LENGTH AGREEMENT FOR THE EUROPEAN 1950 DATUM WITH GSFC '73

TRANSFORMATION PARAMETERS FOR THE EUROPEAN 1950 DATUM AND THE GEOCENTRIC REFERENCE SYSTEM

ΔX	ΔY	ΔZ	Δℓ	OMEGA	PSI	EPSILON
−149.0 ± 3	−103.0 ± 3	−92.5 ± 3	5.0 ppm ± .4	0.″60 ± .08	−1.″9 ± .12	0.″65 ± .08

CORRELATION COEFFICIENTS

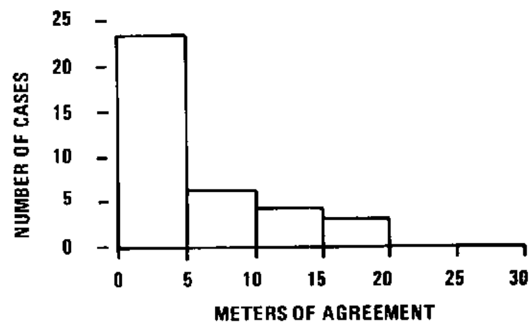
	ΔX	ΔY	ΔZ	Δℓ	OMEGA	PSI
ΔY	.023					
ΔZ	−.481	−0.60				
Δℓ	−.488	−.073	−.512			
OMEGA	−.111	.758	.024	$-.60\times10^{-16}$		
PSI	.863	.049	−.849	$-.13\times10^{-14}$	−.045	
EPSILON	−.089	−.769	.173	$.60\times10^{-15}$	−.190	−.120

RESIDUALS BY STATION FOR EUROPEAN 1950 DATUM ORIENTATION SOLUTION

STATION NAME	NUMBER	RESIDUALS IN METERS X	Y	Z
UZHGOR	9432	0.8	−5.1	1.3
GREECE	9091	1.2	5.5	0.3
1SPAIN	9004	−0.0	4.2	4.3
MUDONI	8030	−5.5	−1.6	−5.5
NICEFR	8019	−3.3	0.5	−4.3
ZIMWLD	8010	1.8	−4.0	−5.1
DELFTH	8009	0.8	3.6	3.8
1WNKFL	1035	−1.2	0.4	7.4
HAUTEP	8015	5.5	−3.5	−2.1
RMS OF FIT		3.0 m	3.6 m	4.3 m

CHORD LENGTH AGREEMENT BETWEEN THE CORRECTED EUROPEAN 1950 DATUM AND GSFC '73 (SATELLITE-SURVEY) IN METERS

	1035	9432	9091	9004	8030	8019	8015	8010
9432	13.3							
9091	1.7	1.1						
9004	2.6	17.2	3.9					
8030	−1.8	12.2	3.1	8.9				
8019	−1.5	10.9	2.4	7.9	0.7			
8015	−4.2	4.8	−2.1	13.5	−1.5	−3.7		
8010	−0.1	5.8	0.8	15.5	2.1	5.5	1.0	
8009	−0.8	15.2	6.7	5.6	−1.1	2.8	−2.5	0.1



HISTOGRAM OF CHORD LENGTH AGREEMENT BETWEEN THE CORRECTED EUROPEAN 1950 DATUM AND GSFC '73

TABLE 21

THE ORIENTATION AND CHORD LENGTH AGREEMENT FOR THE PROVISIONAL SOUTH AMERICAN 1969 DATUM WITH GSFC '73

TRANSFORMATION PARAMETERS FOR THE PROVISIONAL SOUTH AMERICAN DATUM AND THE GSFC '73 GEOCENTRIC REFERENCE SYSTEM

ΔX	ΔY	ΔZ	Δℓ	OMEGA	PSI	EPSILON
−44.1 ± 2	8.0 ± 2	−46.4 ± 2	−1.8 ppm	0.″74	−0.″25	0.″28
			± .2	± .08	± .05	± .08

CORRELATION COEFFICIENTS

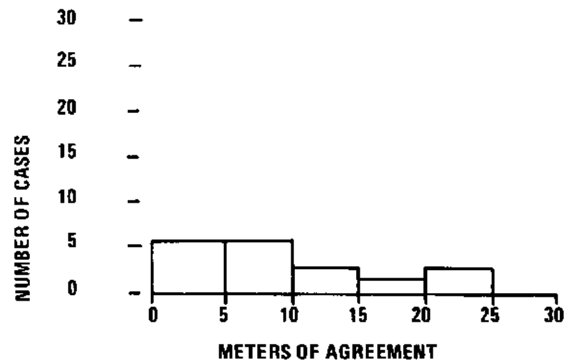
	ΔX	ΔY	ΔZ	Δℓ	OMEGA	PSI
ΔY	.484					
ΔZ	−.424	−.564				
Δℓ	−.295	.481	.276			
OMEGA	.858	.762	−.571	$.97 \times 10^{-15}$		
PSI	−.150	.241	−.532	$.24 \times 10^{-15}$	.211	
EPSILON	.481	.774	−.897	$.93 \times 10^{-15}$	.629	.298

RESIDUALS BY STATION FOR PROVISIONAL SOUTH AMERICAN DATUM ORIENTATION SOLUTION

STATION NAME	NUMBER	RESIDUALS IN METERS X	Y	Z
COMRIV	9031	−4.4	1.3	3.0
NATALB	9029	−1.8	−2.7	−1.5
1VILDO	9011	−1.6	5.9	3.2
1QUIPA	9007	−0.8	1.3	9.9
1SATAG	1028	8.6	−5.7	−14.7
RMS OF FIT		4.6 m	4.0 m	8.2 m

CHORD LENGTH AGREEMENT BETWEEN THE PROVISIONAL SOUTH AMERICAN DATUM AND GSFC '73 (SATELLITE–SURVEY) IN METERS

	1028	9031	9029	9011	9009
9031	5.5				
9029	−9.7	−7.6			
9011	2.1	−1.7	−1.8		
9009	−2.9	9.8	−16.1	9.0	
9007	−21.8	−12.1	−1.2	−11.2	21.7



HISTOGRAM OF CHORD LENGTH AGREEMENT BETWEEN PROVISIONAL SOUTH AMERICAN DATUM AND GSFC '73 are somewhat larger than those for the two previously considered datums with RMS values of 4.6, 4.0 and 8.2 meters, respectively. Table 21 presents these results.

4.4 AUSTRALIAN GEODETIC DATUM AND THE ARC DATUM

Only three separate locations were available for comparison in Australia. Table 22 presents the results for the AGD. The translation and orientation parameter values showed high correlations as might be expected due to the small number of stations. The correlation coefficients for scale were in general less than 0.3, therefore it is concluded that the scale difference of 1.9 ± 0.4 ppm is a well determined value.

Translation parameters are presented below for the two stations on the Arc Datum which were independently adjusted in our solution.

	ΔX	ΔY	ΔZ
Johannesburg, Rep. of S.Africa	-124.2 m.	-108.8	-296.2
Olifantsfontein, Rep.of S.Africa	-125.2	-107.8	-300.8

Comparison of the satellite derived chord connecting these two stations with the surveyed value indicated a difference of 1.9 meters.

TABLE 22

THE ORIENTATION AND CHORD LENGTH AGREEMENT FOR THE AUSTRALIAN GEODETIC DATUM WITH GSFC '73

TRANSFORMATION PARAMETERS FOR THE AUSTRALIAN GEODETIC DATUM AND THE GSFC '73 GEOCENTRIC REFERENCE SYSTEM

ΔX	ΔY	ΔZ	$\Delta \ell$	OMEGA	PSI	EPSILON
-137.2 ± 15	-49.5 ± 5	155.0 ± 21	1.9 ppm $\pm .4$	0.″34 $\pm .26$	0.″18 $\pm .64$	0.″38 $\pm .54$

CORRELATION COEFFICIENTS

	ΔX	ΔY	ΔZ	$\Delta \ell$	OMEGA	PSI
ΔY	–.833					
ΔZ	–.979	.840				
$\Delta \ell$	.095	–.326	.060			
OMEGA	–.969	.711	.944	$.117\times10^{-13}$		
PSI	–.988	.839	.993	$.118\times10^{-13}$	.943	
EPSILON	–.974	.877	.992	$.120\times10^{-13}$	.939	.980

CHORD LENGTH AGREEMENT BETWEEN THE AUSTRALIAN GEODETIC DATUM AND GSFC '73 (SATELLITE–SURVEY) IN METERS

	1038	7054
7054	5.2	
9023	–3.5	9.7

RESIDUALS BY STATION FOR AUSTRALIAN GEODETIC DATUM ORIENTATION SOLUTION

STATION NAME	NUMBER	RESIDUALS IN METERS X	Y	Z
CRMLAS	7054	–1.3	–0.4	–0.2
1ORROL	1038	–2.0	–1.7	–0.7
AUSBAK	9023	3.3	2.1	0.9
RMS OF FIT		2.4 m	1.6 m	0.7 m

4.5 DATUM TRANSLATION VALUES FOR OTHER AREAS OF THE WORLD

Figures 5, 6, and 7 present rectangular coordinate differences (satellite-survey) for the stations considered in the GSFC '73 solution. These tables provide the capability for other investigators to quickly place instrument locations for which local surveys are available into our geocentric reference system for 10 independent geodetic datums. In this way, geocentric positions of better than 10m accuracy can be readily obtained for over 200 additional tracking stations throughout the world.

FIGURE 5. THE TRANSLATION PARAMETERS FOR THE X COORDINATES

BETWEEN GSFC 73 AND THE LOCAL SURVEYS

(SATELLITE-SURVEY) IN METERS

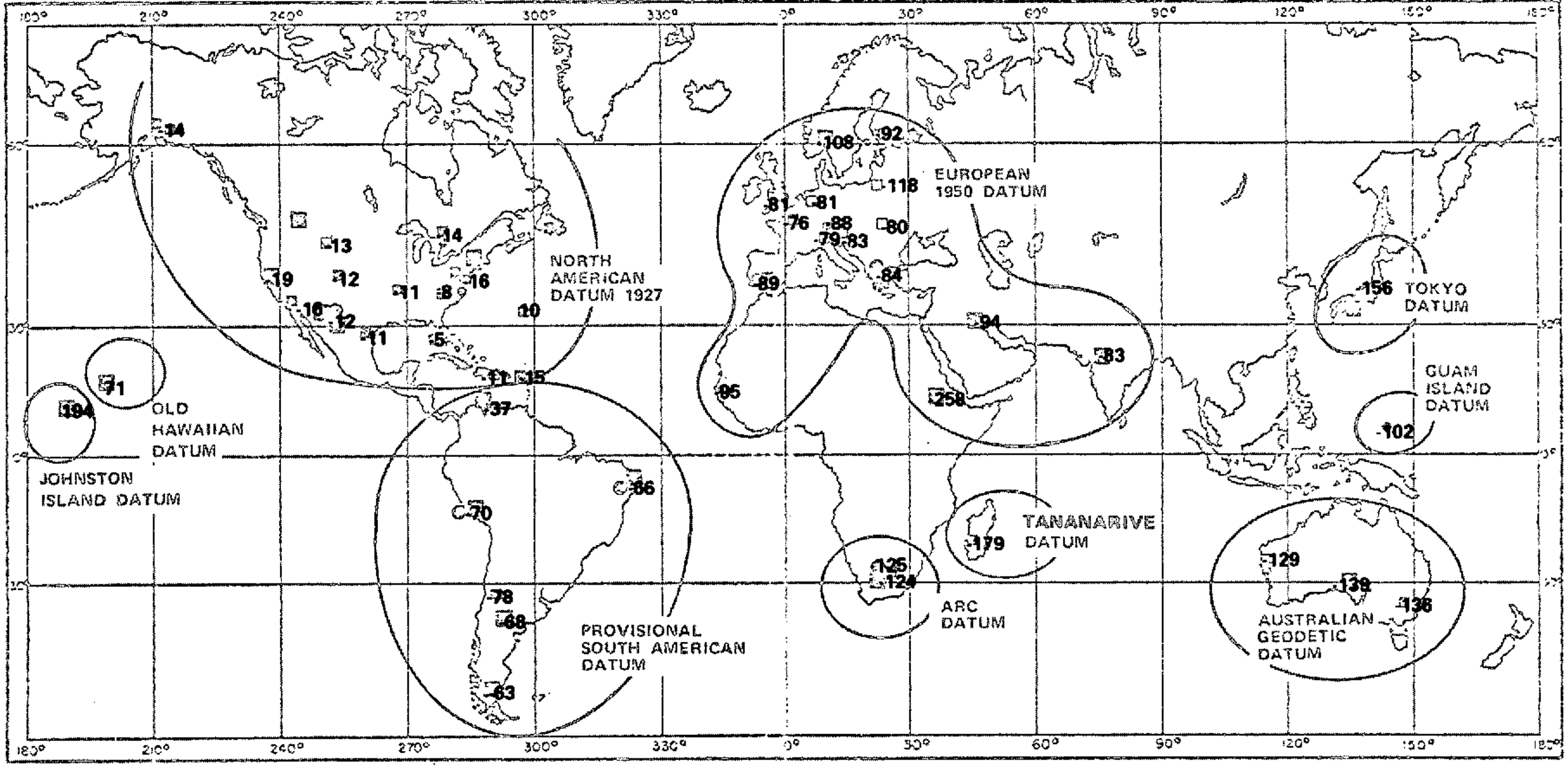


FIGURE 6. THE TRANSLATION PARAMETERS FOR THE Y COORDINATES

BETWEEN GSFC 73 AND THE LOCAL SURVEYS

(SATELLITE–SURVEY) IN METERS

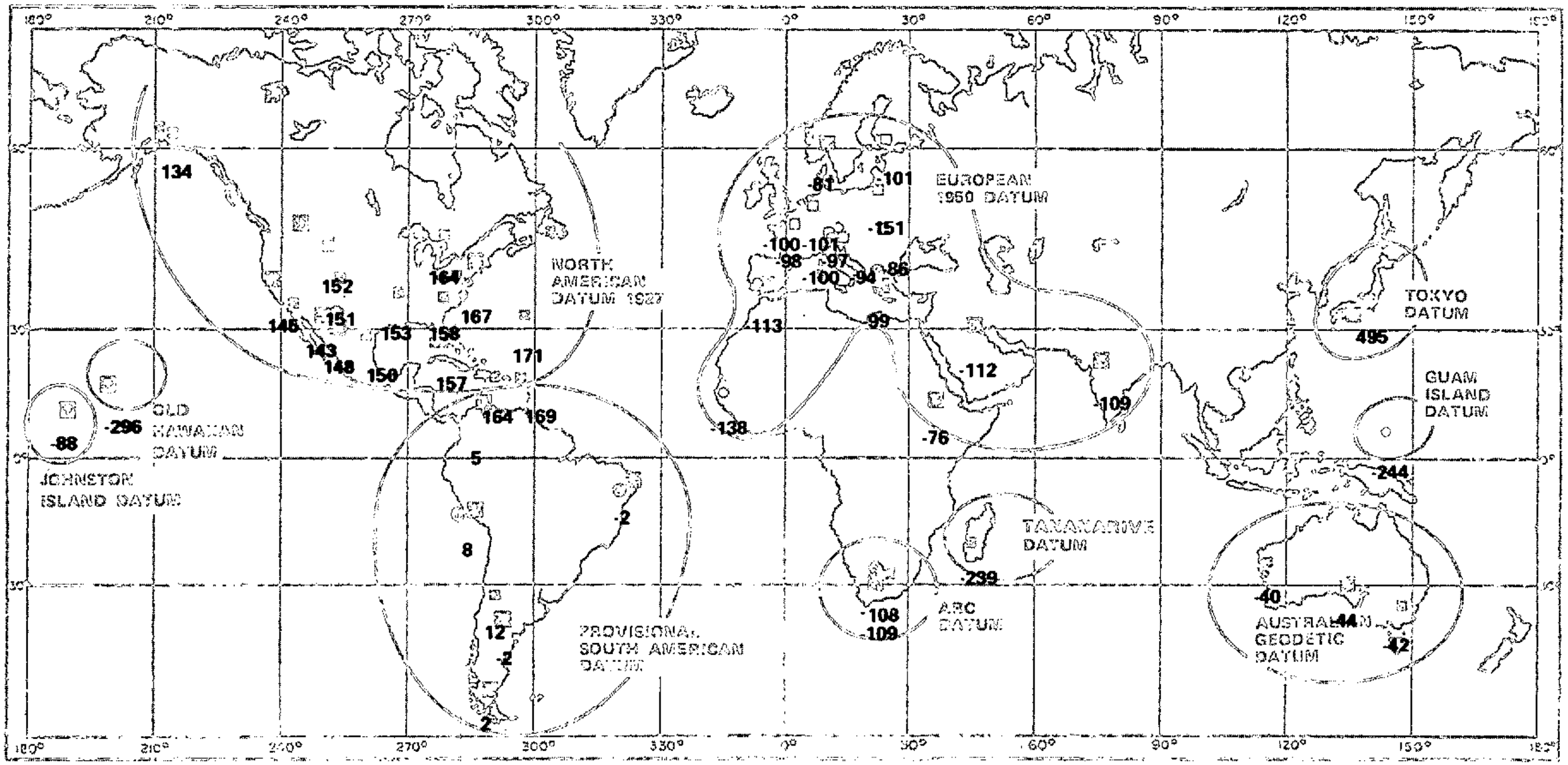
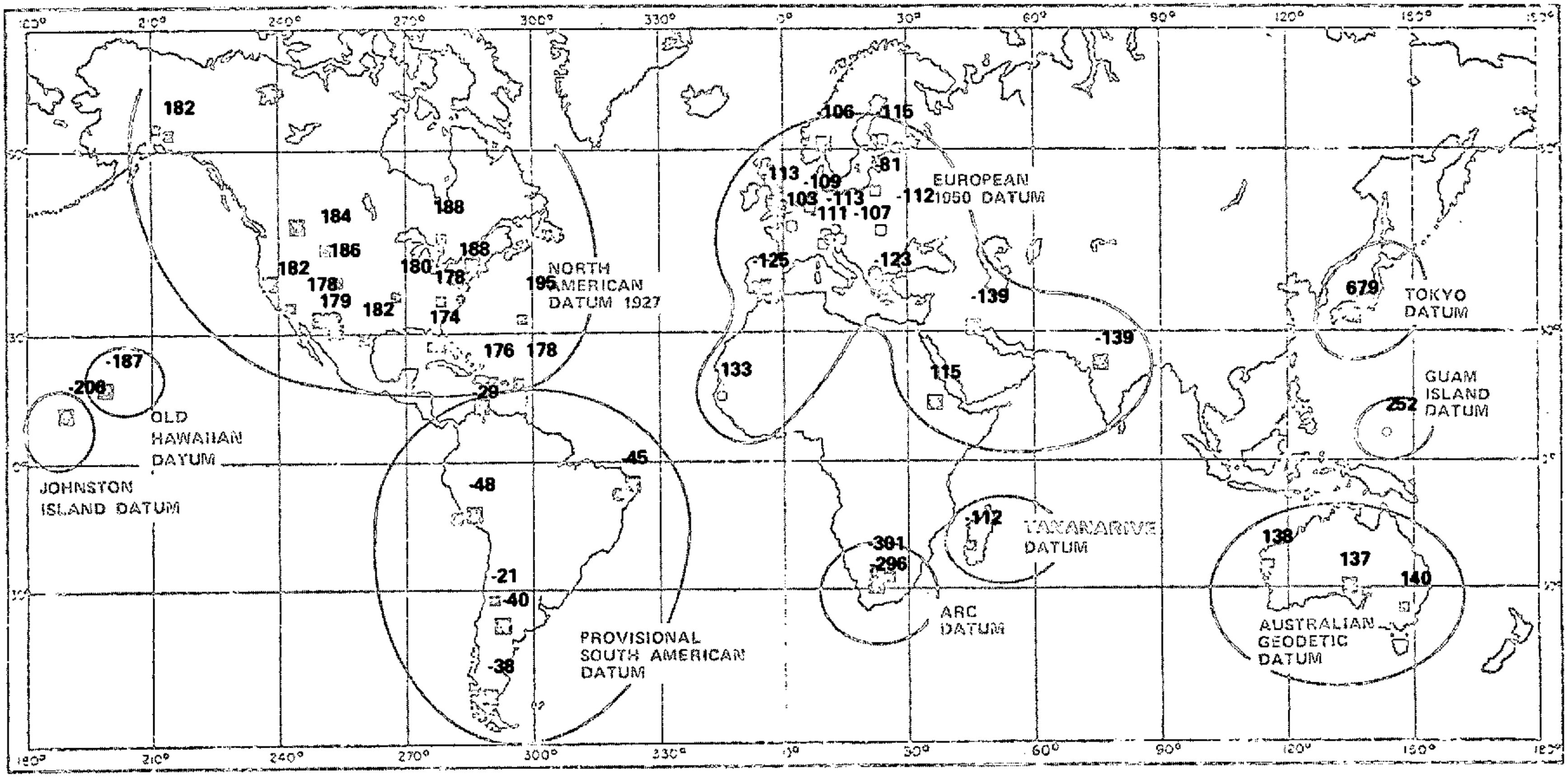


FIGURE 7. THE TRANSLATION PARAMETERS FOR THE Z COORDINATES
BETWEEN GSFC 73 AND THE LOCAL SURVEYS
(SATELLITE–SURVEY) IN METERS



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U.S. GOVERNMENT PRINTING OFFICE: 1973-734-722/39